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Causes, Effects and Control of Defoliation on Tomatoes

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CONTENTS

PAGE

MATERIALS AND METHODS 184

MEASURING INTENSITY OF INFECTION 184

CAUSES OF DEFOLIATION ON TOMATOES 185
- Fungi and Insects 185
- Abnormal Physiology 186
  - Shading 186
  - Age of Tissue 186
  - Fruit Load 188
  - Nutrition 190

EFFECTS OF DEFOLIATION 191
- Total Yield 191
- Marketable Yield or Quality 192
  - Relation to Type of Market 193
  - Poor Quality Types 193
  - Diseases on Fruit 194
- Ripening 195
  - Rate of Ripening 197
  - Rate of Fruit Production 198
  - Harvest Peaks 198
  - Discussion 199

COMBATING DEFOLIATION DISEASES WITH FUNGICIDES 202
- Injuriousness of Fungicides 202
- Performance of Fungicides 205
  - Fungicidal Value 205
  - Tenacity 206
  - Protective Value 207
  - Derivation of Protective Coefficient 208
  - Timing 212
  - Coverage 214

PRACTICAL ASPECTS 217
- To Spray or Not to Spray 217
  - Materials to Use 217
  - When to Spray 218
  - How to Apply Materials 219
- Varieties 219
- Fertilizers 219
- Air Drainage 220
- Miscellaneous Suggestions 220

SUMMARY 220

LITERATURE CITED 222

Causes, Effects and Control of Defoliation on Tomatoes[1]

James G. Horsfall and John W. Heuberger

More than thirty years of research have been directed at explaining the paradox first perceived by Lloyd and Brooks (24) that bordeaux mixture reduces the yield of tomatoes despite its obvious value in controlling the defoliation diseases. This paradox has been particularly baffling in the light of the fact that bordeaux mixture is widely used to improve the yield of potatoes, a plant in a related genus. Farmers would like to reduce the ravages of the defoliation diseases, but they have generally not dared for fear of yield reduction from the fungicides. Lloyd and Brooks (24) initiated a persistent fallacy in stating that bordeaux seems to cause the tomato plants to "continue growth rather than ripen early fruit."

Boyle (1) in 1913 advanced the explanation that the defoliation of non-sprayed vines caused them to "ripen their crop quicker than bordeaux-sprayed vines, so that a larger portion was picked ahead of the killing frost." Edgerton (6) applied the term "delayed ripening" to the phenomenon that underlies the paradox. This label has crept into practically all subsequent papers on the subject of tomato spraying.

The fatalism induced in the subject by the concept that spraying delays the ripening of tomatoes appears to have slowed progress on the problem, because very few papers except those by Wilson (41, 42, 43, 44) have appeared on tomato spraying after completion of the work that happened to be under way when the theory was advanced.

In 1929 the problem of defoliation diseases of tomatoes was taken up at the suggestion of Dr. Charles Chupp, Extension Plant Pathologist at Cornell University, who pointed out the need for a practical control of the diseases. During the intervening 13 years, research has been conducted on various aspects of the problem. Several portions of the results have been published (7 to 22), but an effort will be made in this paper to summarize the important information extant on the causes, effects and control of defoliation diseases of tomatoes as it applies in the Northeast. Particular emphasis will be placed on the problems of ripening of diseased and sprayed tomatoes, and on the problems that are involved in the testing and development of new fungicides for tomato spraying.

[1] The results reported herein are based on research that began in 1929. The earlier phases were conducted while the writers were associated with the New York State Agricultural Experiment Station at Geneva, N. Y. The facilities provided by the Director of that Station and by the Department of Plant Pathology are gratefully acknowledged.

The research was done in cooperation with the Crop Protection Institute.

MATERIALS AND METHODS[1]

The essentials of the field technique have already been published (20). Only a summary is needed here. Begun in 1929, the work has continued in the laboratory, greenhouse and field every year except 1933. Disease data were scarce in the early years of the work because disease itself was scarce in the test plants until September during most years up to 1935 when a mild outbreak occurred. It was negligible again in 1936, but it was serious in 1937 and epiphytotic in 1938. The incidence was low in 1939, but epiphytotic again in 1940 and 1941 in Connecticut.

In all years at least four replicate plots of ten or more plants each were used for each treatment. A wheelbarrow hand sprayer was used prior to 1934, but from 1934 on, excepting where otherwise stated, the sprays were applied with a power outfit with three nozzles per row, 300 pounds pressure, 300 gallons per acre. Sprays were standardized at one pound of copper per 50 gallons making six pounds of copper per acre per application. The standard of reference was 4-4-50 bordeaux mixture.

On some plots in 1938, 1939 and 1941 a knapsack sprayer (Calispray) developing 150 pounds pressure was used.

In taking yield records the apparently ripe fruits were picked once a week, counted and weighed. The picking posed a technique problem not yet completely solved. An attempt was made to pick only ripe red fruit, but this was not easy on defoliated plants, where the fruits invariably developed an orange cast. As a result the criterion of ripening was not always the same for all plots. The picked fruits were frequently sorted for cracks, or fruit diseases or spray injury. At the end of the season the green fruits also were picked, counted and weighed. In some years the green weight of vines was also recorded at the end of the season. In some seasons the fruit was graded according to U. S. standards.

MEASURING INTENSITY OF INFECTION

In studying the defoliation disease of tomatoes, it became necessary to measure the intensity of disease attack. In assessing the value of any treatment, it was necessary to know how many fungous penetrations had been prevented and how much the intensity of infection had been reduced by the treatment.

The defoliation disease of tomatoes is such an interesting disease in this connection that a separate study of this aspect of the problem has been made (18). The chief problem involved was to procure adequate data quickly. Counting actual penetrations (leaf spots) was found to be accurate, but entirely too slow to be really

[1] The writers are grateful for extensive assistance rendered by Messrs. A. E. Dimond, R. O. Magie, A. D. McDonnell, G. E. Nutile, and R. F. Suit.

Messrs. G. and J. Nutile of Montowese, Conn., have provided excellent collaboration in the form of a growing crop and facilities for field work in 1940 and 1941. This help is gratefully acknowledged.

useful. In studies already made on clover leaf spots (12), it was observed that the leaf dies when about 20 percent of the area has been hit. It was assumed that in the case of tomatoes also the proportion of dead leaves reflects directly the number of successful infections produced by the fungus.

McKinney's method (27) for measuring disease attack was adopted, and a study was made of its precision. To avoid bias each plant in the experimental area was examined separately by walking crosswise of the treatments. Each plant was classified into one of five categories of infection based on the leaf area killed by disease attack: 0=disease-free or nearly so, 1=one to 25 percent of leaf area killed, 2=26 to 50 percent of leaf area killed, 3=51 to 75 percent of leaf area killed, and 4=76 to 100 percent of leaf area killed. An infection index in percentage for any treatment is calculated by the following formula:

$$\text{Index}=\frac{\text{summation category numbers}}{\text{no. plants x 4}} \text{ x } 100$$

The 4 in the denominator represents maximum disease and 100 is used to convert to percentage. In dealing with fungicides the infection index is subtracted from 100 to give percentage control which brings the data into line with other toxicological data.

It was found that this method gives precise results, especially for a group of plots, and that its precision was satisfactory even for different times.

CAUSES OF DEFOLIATION ON TOMATOES

The defoliation disease of tomatoes is easy to diagnose. The leaves die and drop, opening up the center of the plant and exposing the fruit to the sun. A study has been made of the various factors that are involved in the causation of the disease, such as fungi and insects, abnormal physiology and weather.

Fungi and Insects

Three fungi have been found attacking tomato foliage in the experimental fields. In the ascending order of importance these are *Cladosporium fulvum*, *Septoria lycopersici* and *Alternaria solani*. *Cladosporium fulvum* is rare. *Septoria lycopersici* has occurred sporadically, but it cannot be considered to have been a major factor in defoliation during the period 1929 to 1941. A survey of the literature indicates that Septoria played a more important role in the causation of the disease prior to 1929 than it appears to have played since 1929.

Alternaria solani has probably been responsible for 90 percent of the defoliation during the same period. Apparently, this organism has captured the major role from Septoria during the last decade and it appears to be still on the increase as a disease producer in tomatoes.

Flea beetles and aphids also cause some defoliation in Connecticut although neither was much of a factor in the plots in western New York. Flea beetles were found by Heuberger and Dimond (9) in 1941 to be seriously involved in the defoliation problem because they punctured the leaves and opened the road to infection. W. H. Martin (25) has indited them also for transporting spores.

Abnormal Physiology

It is becoming increasingly clear that abnormal physiology of the plant is associated with the causation of defoliation of tomatoes. It is not yet clear, however, whether the abnormal physiology is a primary cause of leaf abscission or whether it contributes to susceptibility to fungous invasion. Some people seem to feel that the problem is primarily one of abnormal physiology. One of the important reasons for thinking so is that the defoliation disease in bad years is seldom held more than 50 percent in check by the best fungicides. If fungi were the prime movers in the etiology of the trouble, better control should be obtained.

Shading. Simple shading of the foliage has been offered as the cause of the disease, because shading favors the abscission of leaves. The importance of shading *per se* is certainly minor, as shown by the thousands of acres of unstaked tomatoes where the foliage is exceedingly dense but where no defoliation occurs. Moreover, in years when the disease becomes serious the plants are opened to the sun, but this does not stop the process of defoliation. This is not to say, of course, that shading may not overbalance a situation that borders on susceptibility.

Age of Tissue is certainly one of the most important variables in the susceptibility of tomatoes to defoliation by fungi, as suggested by Moore (28).

Tomato seedlings in the cold frame are sometimes attacked by Alternaria, but this seldom or never occurs until toward the end of their seedbed life when the tissues are becoming old and hardened. The disease on such heavily attacked plants has been observed to disappear as if by magic as soon as the plants are moved into the field and they begin to grow again with much vigorous young tissue. The disease reappears, however, as soon as growth begins to slow down and old tissue begins to predominate. Volunteer plants that start late are not affected as seriously as the older plants that make up the crop. Age of tissue appears to be concerned in the case of the early susceptibility of staked plants. Good air drainage normally reduces attacks by leaf diseases. Staked plants have better air drainage than ground plants, and this shows up as favorable to them by the end of the season. In 1939 the percentage of disease reached 83 for the ground plants but only 63 for the staked plants. Likewise in 1940 it reached 98 and 60, respectively.

Despite the advantage of air drainage, however, staked plants are attacked earlier in the season than ground plants in the same field.

TABLE 1. EFFECT OF DEFLORATION AND FRUIT LOAD ON SUSCEPTIBILITY OF TOMATOES TO DEFOLIATION BY *Alternaria solani* IN 1941

Defloration treatment	Number of days fruit removed	Number of ripe fruits picked per plant									Defoliation percent			
		Aug. 6	Aug. 15	Aug. 26	Sept. 2	Sept. 8	Sept. 15	Sept. 22	Totals to Sept. 8	Totals to Sept. 22	July 21	Aug. 11	Sept. 2	Sept. 11
Begin July 10	42	1.45	2.70	1.60	0.60	1.05	2.55	6.55	7.40	16.50	15.0	35.0	62.5	67.5
Begin July 16	36	2.05	3.40	3.15	2.50	2.45	2.95	6.05	13.55	22.55	13.7	30.5	72.5	70.0
Begin July 28	24	1.55	3.25	2.15	6.10	9.15	2.55	4.25	22.20	28.95	16.3	36.3	82.5	88.8
No defloration	0	1.80	4.05	4.35	5.85	12.75	6.60	5.90	26.80	37.30	15.0	34.3	95.0	96.3
End July 10	10	0.30	0.55	2.05	4.20	13.50	7.00	9.00	20.60	36.60	15.3	32.5	87.5	96.3
End July 16	16	0.10	0.80	1.50	1.45	11.90	17.45	12.60	15.75	45.80	12.0	28.0	82.5	97.5
End July 28	28	0.20	0.25	1.90	1.35	4.60	9.75	16.10	8.30	34.15	11.3	29.3	72.5	82.5
End Aug. 21	52	0.15	0.10	0.55	0.55	1.05	2.35	5.80	2.40	10.55	13.8	30.0	58.8	65.0

TABLE 2. EFFECT OF DEFOLIATION BY *Alternaria solani* ON YIELD OF TOMATOES. DATA EXPRESSED ON A PER-PLANT BASIS

Treatment	Disease category	Number of plants	Ripe fruit		Green fruit		Total fruit		Percent frosted
			Number	Weight, pounds	Number	Weight, pounds	Number	Weight, pounds	
Plants not Sprayed	0	5	29.2	7.46	63.0	10.09	92.2	17.55	68.3
	1	21	41.0	10.86	64.4	10.06	105.3	20.92	61.1
	2	31	42.6	10.74	57.5	7.56	100.0	18.30	57.4
	3	44	49.5	14.24	40.3	7.36	89.80	21.60	44.9
	4	11	53.1	16.40	39.2	7.22	92.3	23.62	41.3
Plants Sprayed Once Early With Bordeaux	0	0							
	1	4	40.0	11.32	62.3	9.59	102.3	20.91	60.9
	2	26	47.4	12.94	60.4	8.00	107.8	20.94	56.0
	3	49	54.1	15.45	50.2	7.27	104.3	22.72	49.0
	4	9	52.4	17.15	34.7	5.56	87.1	22.71	39.8

In 1940, for example, staked plants reached 50 percent defoliation by mid-July, but this level of defoliation was not reached by the ground plants until mid-August. This may be related to age of tissue, because much of the young tissue is pruned out of staked plants, and the basal leaves soon become tough and hard, resembling old leaves.

Fruit Load. Fruit load is concerned with susceptibility to defoliation. It is a common observation first published by Samson (33) for *Septoria lycopersici* that defoliation strikes most heavily on the plants that bear the largest number of fruits. The same relation seems to hold for *Alternaria solani*. What the farmer calls "bull" plants, i. e. those that refuse to set fruit, seldom are afflicted seriously with defoliation. Similarly, the disease seldom or never attacks a crop in the field until after the plants begin to set fruit.

The effect of fruit load was first tested experimentally in 1940. The fruits were removed as they appeared from two groups of ten plants each in a large field. When the defoliation disease struck in late August, it practically passed over the defruited plants, so that they were strikingly green in September when the checks were almost dead. At first it might seem as if the result was an artifact due to the increased foliage that the plant pushes out in response to defruiting. Such was not the case, however, because the stems were also freer of spots on the deflorated than on the non-deflorated plants.

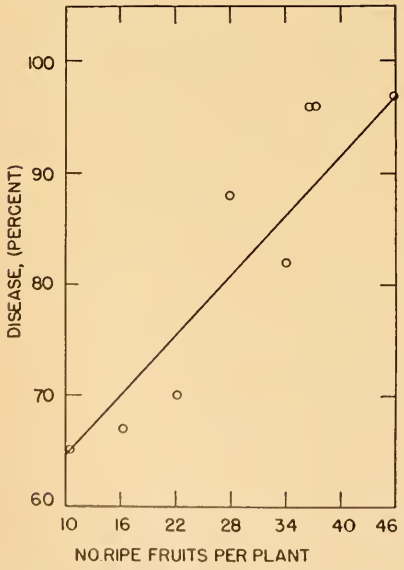

FIGURE 1. Relation of total fruit load to susceptibility of tomatoes to defoliation by *Alternaria solani*.

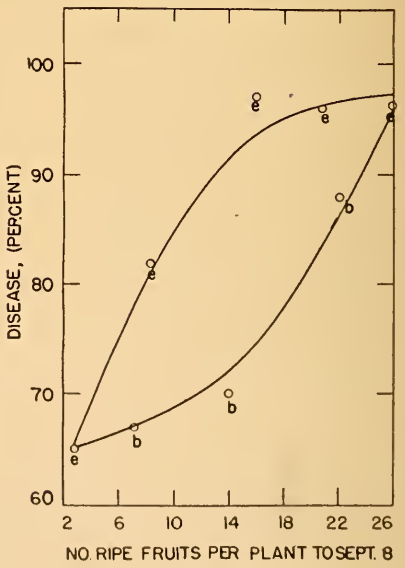

FIGURE 2. Relation of fruit load cumulative to September 8 to susceptibility of tomatoes to defoliation by *Alternaria solani*.

The experiment was elaborated in 1941, using Scarlet Dawn tomatoes. The fertilizer was 3-12-6 applied as side dressing in bands, 500 pounds per acre two weeks after transplanting, and 500 pounds three weeks later. Blossoms began to form in the field about July 1. Beginning on July 10, when each plant had set two or three small fruits, four replicate five-plant plots, randomized in blocks, were laid out for each of the treatments (Table 1). All fruits were removed from some plants and these were kept essentially free of fruit until late August when defloration was discontinued. Other groups of plants were deflorated beginning and ending progressively later. As a result there were groups of plants carrying a few fruits all season, a few at the beginning of the season, a few at the end of the season, and all intergrading conditions.

Data indicate a fairly general relation between fruit load and magnitude of infection (Figures 1 and 2). This finding agrees with the generalization already noted that susceptibility is associated with fruit load. It is surprising, however, that the agreement is as good as it is, because of the variable introduced as to when the fruits were set.

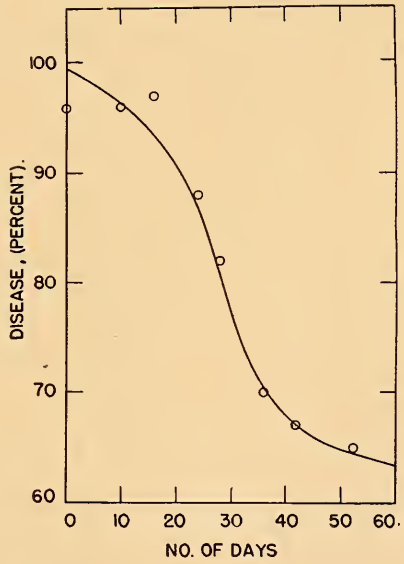

FIGURE 3. Relation of number of days that fruit was removed to susceptibility of tomatoes to defoliation by *Alternaria solani.*

It is to be noted that the checks reached the peak of harvest on September 8. If the total yields up to September 8 are plotted against magnitude of infection (Figure 2) two distinct curves appear, one for plants carrying fruits at the first of the season (labelled e for "end defloration") and one for plants carrying fruits at the end

of the season (labelled b for "begin defloration"). These curves show clearly that, for equal numbers of fruit, the plants carrying fruit early showed more disease than those carrying them late.

This fact suggested that the critical element here is actually the number of days that fruits were picked off. The longer the plants were deflorated, the less disease they developed. Since blooming began about July 1, this can be calculated (Table 1). When these data are plotted against magnitude of infection (Figure 3) the points come very close indeed to a fit on the curve, showing that the number of days that fruit were picked off is actually more critical in predisposition to infection than the number of fruit finally set. This fact confirms the observation noted above that disease seldom attacks until after the onset of fruiting.

Observations indicate that disease usually begins to be somewhat apparent about mid-July to August 1 in western New York and in southern Connecticut. This shows several interesting correlations. Since blossoms are set toward the end of June, this gives the disease two or three weeks to develop after fruits begin to appear on the vines. Steier (36) in Maryland has approached it differently. He says that disease begins to remove the leaves in about 65 to 80 days from planting. Transplanting usually begins about May 20. Sixty-five days from May 20 is July 23. Timing experiments of sprays indicates that July 10 is early enough in most years. Allowing two weeks for incubation, this means that defoliation could be expected to begin about July 24.

Nutrition. A significant correlation of infection and nutrition is worth noting here. Practical men believe as noted above that Alternaria on tomatoes is increasing in importance, at least in the Northeast. Publications from Experiment Stations tend to confirm this. It is suggested that this increase may be due in part to a strong trend in the farmers' practice toward reducing the nitrogen, and increasing the phosphorus in the fertilizer, in an effort to bring about higher fruit loads. Although this practice may increase yield of fruit per acre it may also increase susceptibility to *Alternaria solani* at the same time. Possibly the nutrition balance has been disturbed. Several fields were noted in Connecticut in 1941 where the production of the plants was enormous but the picked yield was low because the disease was so bad.

This problem has been tentatively explored experimentally. In 1940 two groups of ten Scarlet Dawn plants each in a field were heavily fertilized with sodium nitrate (one-half pound per plant) on July 2 and again on July 25. The base fertilizer at planting time was 1000 pounds of 3-12-6 applied in bands at planting time. The nitrated plants grew luxuriantly and fruited poorly as was to be expected on the basis of current fertilizer recommendations. Alternaria attacked the field strongly in August and defoliated the checks early in September, leaving the nitrated plants as green islands in the field. The green island effect, of course, was due in part to the excessive vegetation but, since the stems on the treated plants were

freer of disease than those on the checks, it follows that the treatment had imparted resistance. Additional work should be done on the effect of nitrogen and phosphorus nutrition on susceptibility.

It may be that the results on fruit load and nitrogen nutrition are primarily to be explained on the basis of the physiologic age of the tissues, because both are known to delay senescence of plant tissue. Flower gardeners often pick blooms frequently to keep the plants vegetating and producing more blooms.

EFFECTS OF DEFOLIATION

Having examined the causes of defoliation it is pertinent to examine the effects. A clear understanding of the effects of defoliation should be valuable in clearing up the mystery of "delayed ripening" said to be caused by spraying.

Loss of leaves by defoliation, of course, reduces green weight of the plant. The leaves that are left have to assume the load of carrying along the plant including the growing fruits. This is equivalent to increasing the fruit load, and this probably ages the remaining leaves, so that they become more susceptible than otherwise to Alternaria. The process then snowballs, resulting in complete defoliation and, finally, death.

Total Yield

It is probable that defoliation can have little effect on total fruit production in the Northeast, because most of the crop that can be picked ahead of frost is already hanging on the vines before the disease attack can become serious.

At first glance this statement seems at variance with the preceding discussion that disease attack is associated with fruiting. The inevitable lag, however, is the responsible agent. Fruits begin to appear by late June, but their effect on the plant appears to go through a lag period, so that initial infections do not begin until well along in July. Several days are required for each spore generation and as a result disease seldom attains sufficient momentum to induce much defoliation until mid-August or later. By that time it is too late to obtain fruits from the blossoms that set. Tagging experiments with blossoms described in more detail below have shown that nearly 60 days are required to ripen the crop. That means that fruits set after August 1 have small chance of being picked ahead of frost in the Northeast.

Three divergent approaches are possible in measuring the effect of disease on yield: (a) comparison of diseased with healthy fields, (b) comparison of diseased with healthy plants, and (c) comparison of diseased non-sprayed plants with plants kept in various stages of defoliation by different sprays.

Practical farmers use the method of comparing healthy fields with diseased fields and comparing yields in disease years with yields in disease-free years. They are all in agreement that the disease re-

duces the yield of the fruit that they can pick, but this is a problem in marketable fruit which will be discussed below. No data is available for making such comparisons of total yields of fields.

In 1929 the problem was investigated using individual plants. In that year all the ripe fruits on each of the 552 plants in a spray experiment were picked each week. The intensity of infection on September 18 was obtained for each plant as described. Consequently data are available on the yielding performance of individual plants, both sprayed and non-sprayed, that carried different amounts of disease at the end of the season.

The total yields were assembled by disease categories for 112 non-sprayed plants and for 88 plants sprayed only once early with bordeaux (Table 2). Results were clear cut and identical for the two groups of plants, but the implication differs depending upon how they are stated. The results may be stated in the form that the yield of ripe fruits increases as the disease increases, or they may be said in the form that the most prolific plants developed the most disease. This latter method of arranging the statement is probably the more accurate, because other data just discussed show that the prolific plants do develop the most disease.

Upon pursuing the matter further it appears that the green fruit acts contrariwise. As disease increases green fruit decreases. A further step in the analysis shows that the proportion of ripe fruit increases as disease increases. In practice this means that more fruits on defoliated than on non-defoliated plants are picked ahead of frost. Sometimes this statement is put in the form that they ripen ahead of frost. This brings up the fallacy that disease accelerates ripening because that explanation can be offered to account for the fact that most of the crop on defoliated plants is picked ahead of frost.

This matter will be considered in more detail below.

Marketable Yield or Quality

If it seems difficult to measure the effect of disease on total yield because of the complication of high yield, high disease, it is even more difficult to measure the effects of disease on quality yield. Quality in tomatoes is an ill-defined concept, and the concept changes from market to market and from season to season. When tomatoes are all good, the market is choosy as to quality; when they are all mediocre, the market takes almost anything. When prices are poor, quality must be excellent if the fruit is to move. When prices are good, anything moves.

Brown in 1928 (2) seems to have made the only attempt to measure the effects of disease on yield of marketable fruit. Early in August he surveyed 1,991 acres of canning tomatoes in several Indiana counties and rated each field as to whether infection was slight, moderate, or heavy. He obtained data from the canning factories on tonnage purchased. He found that 1,199 slightly diseased acres produced 3.47 tons of marketable fruit per acre; the 519 moderately diseased acres yielded 2.79 tons per acre, and the 273 heavily dis-

eased acres yielded 2.26 tons per acre. Assuming 3.47 as a normal yield of marketable fruit for the area for that year, it may be deduced that a medium attack reduced the yield by 19.3 per cent, and that a severe attack reduced the yield by 34.5 per cent. This finding is precisely in line with what farmers think in relation to the effect of defoliation on yield of fruit that they can sell.

Defoliation induces or aggravates certain off-quality conditions, such as flabbiness, cracks, sunscald, orange instead of red color, and off-flavors. It also aggravates such diseases as stem-end rot, anthracnose, and soil rot.

Relation to Type of Market. The effect of these factors on marketability depends, of course, on the needs of the market concerned. Flabbiness, cracks and fruit diseases are reflected in salability in almost any market except the most bearish. Color, however, is of critical importance to the canner and roadside markets. The canner constitutes a very critical market and he now buys largely on U. S. grades which are based on color, presence of mold and size.

Poor Quality Types. Pickers often note that fruits on defoliated plants are more flabby than those on normal vines. Fruits on defoliated plants also crack much worse than those on non-defoliated plants. This reduces the marketability of the fruits in almost any market, perhaps more in the local market than in the cannery, because the canner may pare out the cracks. Cracks reduce marketability also by permitting the entrance of rot-producing organisms that reduce the fruit to a skin full of slime. The probable reason for the increase in cracking of fruits on defoliated plants is that they do not have the leaf tissue to soak up the extra water that the roots take in during a rain. There may also be a reaction to light. Fruits grown in heavy paper bags in 1940 cracked much less freely than those not so bagged. Presumably this was a matter of light.

The exposure of fruits to strong sunlight when leaves fall often results in sun scald which makes the fruit wholly unsalable. This may be a serious factor immediately following the loss of the leaves if a hot spell occurs.

The flavor of fruits appears to diminish as the defoliation increases. This factor is almost undefinable, but it is probably associated with a lowering of sugar content. The fruits seem to be insipid, flat, or even mildly sour.

Probably the most important factor in lowered quality that comes from defoliation is the poor color as first reported by Pritchard and Porte (31). Fruits on severely defoliated vines seldom or never attain a normal deep red color, but rather they reach an orange red color that is not acceptable to a critical trade like a cannery or a roadside market. However long such fruits remain in the field, they remain a sickly orange, never becoming rich red. In one severely diseased field in Connecticut in 1941 more than 50 fruits per plant were left unpicked in the field because they would not "color up."

A study of some of the possible causes for this effect of defolia-

tion on color are interesting. In 1913 Duggar (5) showed that the red color (lycopene) in tomatoes is closely limited by temperature. Lycopene forms very slowly at temperatures below 55°F. This accounts for poor coloration of fruits in the fall. Likewise, the color is not formed if the fruit temperature rises much above 85°F. Rosa (32) showed in 1926 that the yellow pigment (largely carotin) forms quite readily at a temperature of 85°F. or above. MacGillivray (26) then showed in 1935 that the temperature of the fruits on defoliated plants may rise as much as 20°F. higher than that of fruits on non-defoliated plants nearby. He concluded that these elevated temperatures encouraged the yellow color and discouraged the red color, thus giving rise to orange colored fruits.

In 1936 Ora Smith (35) investigated the effects of light on tomato ripening in connection with his studies of artificial ripening. He found that light favored the development of the yellow carotinoid pigments and discouraged the developed of the red lycopene. In some tests here in 1940 fruits on staked vines were enclosed in heavy paper bags. When they ripened the color was beautifully rich red instead of the typical orange red of the fruits ripened as they hung from the stakes in the sun. It follows that both light and temperature are concerned in the differential coloration of fruits exposed in the sun when the leaves die and fall away from them.

Diseases on Fruit. Loss of leaves, produced by disease or by hand, appears to increase the susceptibility of fruits to anthracnose or ripe rot caused by *Colletotrichum phomoides.* Anthracnose appears to be on the increase in the Northeast, probably because defoliation is on the increase. The disease occurs as rounded sunken spots with a smooth margin. They look as if they had been pushed in by an index finger without a finger nail. The sunken area is covered with minute pimples arranged in circles. The pimples usually turn dark in late stages. Sometimes anthracnose is called nailhead in Connecticut. This is a misnomer as that name was coined for an entirely different disease found only in the South. The name anthracnose or ripe rot is preferable.

Stem-end rot may sometimes occur plentifully on defoliated plants as it may be caused by *Alternaria solani*, the fungus commonly associated at present with defoliation in the Northeast. This disease produces a black sunken area around the stem sometimes spreading irregularly out onto the shoulder of the fruit.

It probably attacks these areas because the spores fall there and find conditions suitable for penetration. It may sometimes attack cracks as well. On occasion as in 1938 it may cause widespread dropping of fruits when the infection spreads to the pedicle and kills it.

Infection originating from soil borne organisms sometimes seem to be related to defoliation but counts in New York in 1938 and in Connecticut in 1940 failed to demonstrate the effect. Other fruit diseases such as nailhead, bacterial spot and blossom-end rot do not appear to be aggravated by defoliation.

Ripening

The effects of defoliation on ripening is a complex but exceedingly interesting problem, that has been the subject of much speculation in the literature. The problem arose out of an effort to explain early results on the effects of spraying on yield of tomatoes. Two opposing points of view have been evolved, one that spraying delays ripening, the other that defoliation accelerates ripening. Although some data have already been presented (20) on this subject, it will be analyzed here in more detail because more data have become available.

Lloyd and Brooks (24) in 1910, Boyle (1) in 1913, and Edgerton (6) in 1914 to 1918 are chiefly responsible for the prevailing points of view on ripening. They designed their experiments essentially alike and they all obtained essentially the same results which have been duplicated many times since (40, 43). They sprayed some plants with bordeaux and kept some not sprayed. They picked the fruit as it ripened and they examined the picking curves, expressed either cumulatively or as frequencies.

One phenomenon is characteristic of all curves. The picking curves for the sprayed plants are flatter in the beginning of the season and they reach the peak of the harvest later in the season than those for the non-sprayed plants.

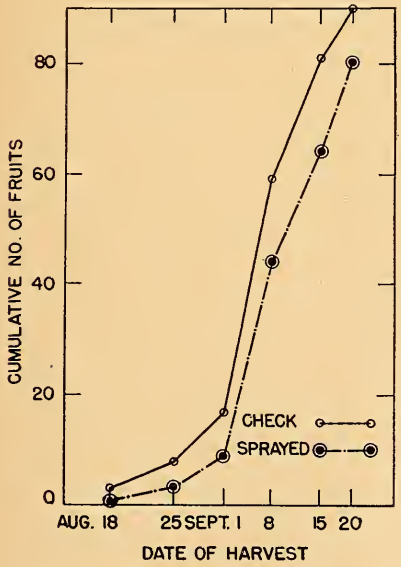

FIGURE 4. Cumulative harvest curves of tomatoes sprayed with bordeaux mixture and not sprayed in a mild disease year, 1937.

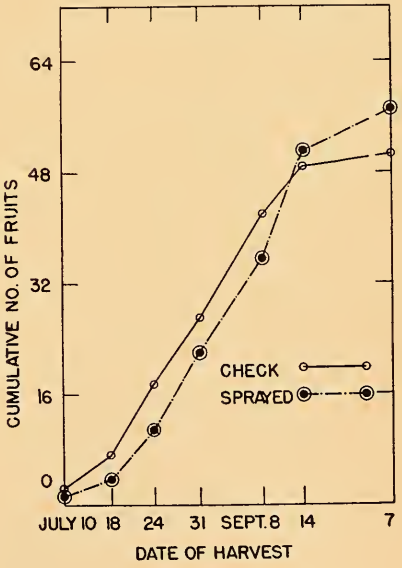

FIGURE 5. Cumulative harvest curves of tomatoes sprayed with bordeaux mixture and not sprayed in a severe disease year, 1938.

In addition, there are two distinct types of curves best expressed as cumulative curves (Figures 4 and 5). In the first type the curve for the sprayed plants remains below that for the non-sprayed plants throughout the season. In the second type the curve for the sprayed plants overtakes and finally passes that for the non-sprayed plants.

Both of these types have been obtained in the present research. The picking curves obtained in 1937 when disease was light illustrates the first type. The curve for the non-sprayed plants remained always ahead of that for the bordeaux-sprayed plants (Figure 4), so that by the end of the season the non-sprayed plants had yielded more ripe fruits than the plants sprayed with bordeaux mixture.

The picking curves obtained in 1938 (Figure 5) when disease was heavy illustrate the second type. Although the curves for the non-sprayed plants forged ahead of that for the sprayed plants early in the season, it began to lose pre-eminence by early September. The curve for the sprayed plants passed that for the non-sprayed between September 8 and September 14.

The work on tomato defoliation almost invariably shows that the sprayed plants retain more green fruits at frost time than non-sprayed plants. This fact has been used as an indirect measure of amount of disease (18).

Upon examining these two types of curves Lloyd and Brooks (24) concluded that the spray caused the plants "to continue growth rather than ripen early fruits." Boyle (1) concluded that defoliation of the non-sprayed vines caused the plants "to ripen their fruit quicker" than bordeaux-sprayed vines, while Edgerton had difficulty in deciding between the two possibilities saying that "This partial defoliation of plants causes a more rapid development of the fruit.....Holding this foliage by means of sprays produces greater vegetative growth and slower development of the fruit." Edgerton apparently leaned toward the latter explanation because he titled his paper "Delayed ripening of tomatoes caused by spraying with bordeaux mixture." This explanation has been retained even up to 1940 (40, 41), despite W. H. Martin's conclusions in 1920 (25): "It is not believed that the presence of bordeaux mixture.....on the plant has any direct influence on the ripening period."

It is well to examine the major premise in the arguments. The major premise is that the slope of the picking curve is a function only of the rate of ripening. The alternative premise is not considered—that the slope of the picking curve is a function of the rate at which blossoms and then fruits are produced. The latter assumption is so simple that it seems strange that the former could have been adopted at all without disproving the latter, at least.

The situation perhaps arose because of the point of view that many farmers hold. When a farmer picks one field ahead of another he often says that it ripened earlier. Probably all he is aware of is that he picks more ripe fruit in the early part of the season from one field than from another. This is a confusion of the concept of the ripening or reddening of a fruit with the production of ripe fruit

from a field. It is then desirable in clarifying this matter to limit the term, ripening, to the rate of maturity (reddening) of fruits, not to the rate at which a field produces red fruits.

In the case of the problem in hand, it is imperative to decide whether the difference between the picking curves is due to differences in rate of fruit reddening or to differences in the rate at which fruits are produced. Experiments must be designed to keep the two separate. At the same time the experimental design must also be capable of keeping the effects of spraying separate from the effects of disease.

Rate of Ripening. The effects of spraying on ripening has to be determined first in the absence of disease. The rate of ripening is found most certainly by tagging blossoms. In 1936 drought was so serious that disease never appeared in the plots in any quantity. Bordeaux was applied all season. All the blossoms that appeared were tagged on ten sprayed plants and on ten non-sprayed plants. The number of days for the average fruit to ripen was 54.1 and 54.9, respectively. Clearly the spray exerted no effect on rate of ripening in the absence of disease. This agrees with Martin's conclusion (25).

The effect of defoliation in the absence of fungus was tested in 1937. From the 1936 data just presented, it was known that fruits set after August 15 could not possibly be picked as ripe before frost. Accordingly fruits were allowed to set normally until mid-August on sprayed plants. Then half the leaves were removed by hand from 80 plants in four replicates of 20 plants each. Fruits were picked as usual and curves were plotted (20). Since the curves could be superimposed, it follows that mechanical defoliation at least had no effect on the slope.

It is commonly held that pruning to a single stem accelerates ripening. Watts (39) tested this hypothesis experimentally by tagging blossoms on pruned and non-pruned tomato plants growing in the greenhouse. Fruits on pruned plants ripened in 43.3 days and they ripened in 43.4 days on non-pruned plants. Here also it is clear that defoliation had no effect on rate of ripening.

The possibility remains, however, that defoliation by disease may act differently from mechanical defoliation in its effects on ripening. Accordingly, in 1941 blossoms were tagged on six bordeaux-sprayed Victor tomato plants that lost less than 20 percent of their leaves during the season and on six non-sprayed plants adjacent that lost more than 80 percent of their leaves from *Alternaria solani* by September 1. The 65 fruits tagged on the sprayed plants ripened in 51.6 days and the 162 fruits on the defoliated plants ripened in 50.9 days.

Clearly the defoliation from disease effected the same results as artificial defoliation or pruning. It had no measureable effect on the length of time from pollination to ripening and hence no effect on rate of ripening. Since neither spraying nor defoliation has exerted any measurable effect on rate of ripening, it seems that the alternative premise needs study—that picking curves are a function of rate of production.

Rate of Fruit Production. The effect of spraying on fruit production has to be determined in the absence of disease. This subject has been investigated in considerable detail (20) and it will be summarized below. It is only sufficient for the purposes here to state that bordeaux dwarfs young plants so that the rate of blossom production is slowed. In the case of the 1936 experiment noted above for tagged blossoms, the 10 sprayed plants produced 44 young fruits during the peak bloom period of July 21 to 28. The 10 nearby non-sprayed plants produced 164 young fruits, or four times as many. The picking data 54 days later showed that all 44 sprayed fruits were picked between September 9 and 16, and that 157 of the 164 non-sprayed fruits were picked. Clearly the higher picking rate of the non-sprayed plants was due to a higher production rate, not to a faster ripening rate. The assembly line moves at the same rate of speed for both sprayed and non-sprayed fruits, but the units are spaced farther apart for sprayed plants than for non-sprayed plants, so that fewer units per week come off the end of the belt.

Harvest Peaks. The experimental work so far appears to explain adequately the smaller production of bordeaux-sprayed fruits early in the season, but this work does not explain the fact that the yield of bordeaux-sprayed plants often overtakes that of the non-sprayed plants and may even surpass that of non-sprayed plants in severe disease years as in 1938 (Figure 5).

Also the experimental work so far does not account for the fact that sprayed plants practically always produce more fruits than the checks in the pickings at the end of the season. Frost often destroys this portion of the crop. This fact has often been advanced in support of the argument that defoliation accelerates ripening. The argument is that, if a larger proportion of the crop is picked ahead of frost from the sick plants than from the healthy plants, then the speed of ripening must be accelerated by defoliation.

Since the tagging experiments show that defoliation does not accelerate ripening, some other mechanism must be sought to account for this effect at the end of the season. If the cumulative picking curves are converted to frequency curves, as those published by Edgerton (6) and those obtained in this work in 1938 (Figure 5), it is clear that the checks reach the peak of picking one or two weeks ahead of bordeaux-sprayed plants.

It has already been shown (20) that tomato plants set fruit in proportion to their size. Since non-sprayed plants grow faster than those sprayed with bordeaux, it follows that they will begin to set fruits quicker; they will attain their maximum growth earlier in the season and, accordingly, the peak of picking will occur earlier in the season.

On the other hand disease usually begins to become serious by the time the unsprayed plants approach the peak of maximum growth and maximum fruit setting. It not only slows growth down, but it may actually cause the plant to lose green weight. When that occurs the plant ceases abruptly to put on new fruits, so that the picking

curve may be truncated. Plants with less disease are able to lay on new tissue faster than the disease removes it. As a result they continue to increase in total green weight and to set fruits. The peak of the picking is thus displaced toward the frost end of the season. This leads to the fact that frost destroys a larger proportion of fruits on non-defoliated than on defoliated vines. In short, the non-diseased plants continue in the normal fashion to produce fruits, with the result that some are caught by frost. They would continue to produce fruits indefinitely unless frost came. The defoliated plants can no longer set a crop, however, and so frost catches but a small proportion of the crop.

It follows that two factors account for a large proportion of fruits at frost time on sprayed plants: (1) dwarfing forces the peak of production later in the season and (2) non-diseased plants continue to add green weight and accordingly blossoms, while diseased plants lose green weight and cease to set blossoms that might produce fruits to be killed off.

Discussion. Since the effect of disease on ripening is such an important subject in the tomato defoliation problem it will be summarized and discussed here as a whole. These studies of the problem indicate that neither disease nor spraying has any effect on the speed at which fruits ripen. The slope of the picking curves is governed wholly, it seems, by the rate at which young fruits are "set" by the plants. The flatness of the slope of the picking curve for sprayed plants early in the season and the lateness of the peak are due to the dwarfing and defloration action of the sprays. The flatness of the picking curve for defoliated plants late in the season and the small percentage of green fruits caught by the frost are due to failure of the plants to continue to set fruits after disease becomes serious.

Pritchard and Porte (31) attempted to kill the theory of delayed ripening at its inception by reporting data from many experiments showing that spraying did not affect the picking curve. Their criticism failed to register, however, because their data were of the same type as that used to set up the theory, i. e. picking data. It was only a question of one set of positive picking data against a negative set of picking data derived by Pritchard and Clark (30). The fact was that the picking curves from sprayed plants are frequently flatter than those of non-sprayed plants. No amount of tests where this effect fails to appear can really disprove it. W. H. Martin (25) almost solved the problem in 1920 by pointing out that bordeaux itself probably had nothing to do with ripening, but that it maintained the leaves which shaded the fruit, "thus delaying its ripening." Martin seemed to recognize that the "spray applications greatly influenced the production of ripe fruit." It seems unfortunate that he did not explore the effect of sprays on production, not on ripening, because his conclusions would have been different if he had.

Smith and Zimmerley (34) plot harvesting curves and they recognize an effect of spraying on time of ripening. If they had examined the "time of ripening" on the basis of time of fruit set, in-

stead of rate of ripening, it would not have been necessary to reinvestigate the problem 20 years later.

J. D. Wilson of Ohio (42, 43, 44) has made many observations of the effects of sprays on vegetables. He has explained several of these as instances of delayed ripening. It is interesting to inspect these observations in the light of the hypothesis that spraying has no effect on speed of ripening, but rather that the effects are due to differences in production rate. Wilson (41) reports that "net increases in yield due to spraying are finally obtained if, and frequently only if, defoliation of the untreated controls is severe enough to cause a considerable decrease in yield."

"This injury trend ..... had to be offset by the beneficial effects of disease control before any net increase due to spraying could be obtained. The existence of this injury zone fails in some instances to give a net increase in yield over similar but untreated plots." One of the classic examples of reduced yields due to spraying involves tomatoes..... Septoria leaf spot was severe enough (in 1938 and 1939) "that many of the spray materials used gave sufficient disease control to offset the injury factor of spraying, with the result that sprayed and dusted plots consistently produced a greater quantity of fruit than untreated ones." As usual, however, the picking curves were flatter for the sprayed plants than for the unsprayed plants and, as usual, this flat slope could easily be explained by the injurious effect of the spray on production of flowers and fruit set. Wilson feels that "ripening of the fruits was delayed long enough that production from some of the sprayed plots did not exceed that of the untreated controls until near the end of the picking season."

Wilson (41) offers as another example of delayed ripening of muskmelons, the fact that materials change ranking as the season advances. In the case of a material such as Compound A that yields poorly at the beginning of the season and high at the end Wilson feels that the ripening is delayed.

It is worth while to study the comparative shifts between Compound A and Cupro K. Compound A ranks low early in the season and high late in the season. Cupro K ranks high early in the season and low late in the season. If compound A delays ripening, then does not Cupro K accelerate ripening?

Either conclusion is more easily explained on another basis. Both materials are oxychlorides and both materials possess approximately equal tenacity. The copper in Compound A has a higher spore killing power than that in Cupro K and it is more injurious on copper sensitive foliage such as lima bean according to Wilson's data. Compound A also has a higher protective coefficient than Cupro K.

The theory of reduced fruit production would give the following explanation: since Compound A is more injurious to tomatoes than Cupro K it would give lower early yields, but since it is relatively more protective against disease, it would give higher late yields.

If the words, tribasic copper sulfate, are substituted for Cupro

K in the preceding discussion, the general picture is the same and it fits the facts equally well.

Wilson (41) offers still another interesting case of delayed ripening. Since cucumbers for seed are picked at the end of the season, there is no question of criterion of ripening and the yielding potentialities are all realized at the end of the season. In one experiment the yield of cucumber fruits was somewhat higher on Compound A-sprayed plants than on tribasic copper sulfate-sprayed plants, but the Compound A-sprayed plants had distinctly fewer seeds than the tribasic-sprayed plants.

The explanation is offered that the seed production was halted in mid-season by mosaic and since "fruits in the plot which had been treated with Grasselli Copper A were the greenest .... they produced the smallest amount of good seed per pound of fruits .... It seems likely that the premature arresting of seed devolpment in the fruits on affected plants may have increased the vegetative growth sufficiently to account to some extent for their greater weight at harvest time."

The major premise here is that mosaic arrested seed development. It seems equally plausible that the copper in Compound A killed more pollen, as it does more spores, than the copper in tribasic sulfate, and hence the fruits carried fewer seeds at the end of the season.

Even if mosaic were accountable for the low seed yield an alternative explanation is possible. On account of differential injury, the tribasic plots were carrying mostly big early fruits with seeds already set when mosaic struck. The Compound A plots were carrying mostly late set small fruits with immature seeds when mosaic struck. This explanation involves later production and later picking, not later ripening.

Finally, the theory of delayed ripening suggested to Wilson (42) that a farmer spray one portion of a tomato field with tribasic sulfate and one with copper Compound A in order to spread his picking load. On the theory of differential production, not differential ripening, the farmer would apply Compound A heavily early in the season to one portion of his field, to kill off a lot of blossoms and give good protection. This portion of the field would reach peak production late. To the other portion of the field he would apply Compound A lightly and late. He would pick this portion early.

One aspect of this ripening that has not been emphasized in the text, because no data on the point are available from these tests, is the effect of defoliation in elevating the temperature of the fruit and the effect of this temperature elevation on speed of coloration. Rosa (32) picked fruits at comparable stages and stored them at various constant temperatures. The rate of ripening in days was 24 for 11°C., 16 for 16°C., 8 for 25°C., and 11 for 30°C.

MacGillivray (26) has ample data to show that defoliation elevates the fruit temperature, even as much as 10°C. The data at New Haven in 1941 show that fruits on defoliated plants ripened no faster than those on non-defoliated plants. The fruits were yellow

red and not red, of course, but they could not be picked for peak color, any sooner, on account of it. How does this fit with the above data?

The explanation would appear to be that the fruits on defoliated plants were generally warm enough to ripen at almost maximum speed. Any advantage of the extra warmth derived from the sun in ripening the fruit was offset on defoliated plants by the possibility of overheating them. Overheating reduces the speed of ripening according to Rosa.

COMBATING DEFOLIATION DISEASES WITH FUNGICIDES

During the period of this research on tomato defoliation an extensive study of fungicides has been made. It was obvious to begin with that bordeaux was depressing the growth and yield of tomatoes. One prime objective was to investigate the causes for this. Much of the work on this objective has already been published, but it will be summarized and supplemented herein.

The second objective was to develop new fungicides to combat the disease without injury. As a part of this objective it was necessary to investigate the properties of fungicides and learn why they perform as they do.

Injuriousness of Fungicides

The research on injury has been confined to copper fungicides. The effects of bordeaux mixture on ripening have just been discussed, but the reasons why bordeaux depresses fruit set and therefore picking were not included.

The timing of sprays is related to injury. Measurement of injury, of course, is complicated by the effects of disease control that tends to parallel injury. It has been shown that the amount of green fruit at frost time measures disease control (18). Green fruit, therefore, cannot serve as a good measure of injury. Likewise, the last one or two ripe harvests tend to measure disease control rather than injury.

It has been decided, therefore, to use as a measure of injury the cumulative ripe yield up to the date when the non-sprayed plants reached the peak of their picking curve. In 1936, the plants remained essentially free of disease on account of drought, but the drought exaggerated spray injury. Three materials were compared: bordeaux mixture, red copper oxide, and red copper oxide plus cottonseed oil emulsion. In one series four applications were applied prior to commencement of blooming on June 26, and in the other series 12 applications were applied all season ending September 1.

The checks reached their peak of ripening on September 14 and the yield, up to that date, was 2.76 pounds per plant. Bordeaux applied all season reduced the yield to 0.72 pounds. If the applications were all applied ahead of blooming, the yield was reduced only to 2.63 pounds per plant.

The timing experiment was reversed in 1938. Four applications were made late in the season, after August 1, instead of early, ending June 26. The all-season sprays were used for comparison. The checks reached their picking peak on September 8, 1938, and the yield up to that date was 4.22 pounds per plant. Bordeaux applied all season reduced the yield to 3.56 pounds per plant but, when applied after August 1, the yield was 4.0 pounds per plant. It is clear that withholding the applications until the middle of the season essentially eliminates the injury. From these two timing experiments, it follows that sprays applied either before blooming begins or after blooming ends are less injurious than those applied all season.

The causes of this depressing action are not far to seek. The comparative performance of bordeaux and red copper oxide immediately indicates lime (22) because lime is the outstanding difference between bordeaux and red copper oxide. The effects of lime have been investigated extensively both on tomatoes (14) and on cucurbits (15). lime, especially hydrated lime, appears to be definitely deleterious when applied to foliage of these plants. If cuticles are thin, it appears to saponify them (14) so that water escapes readily. This effect may be minimized if cuticles are old and hard, however.

Lime appears to enter the tissues and to make them tough and harsh. In 1939 Dr. R. F. Suit of the New York State Experiment Station made puncture tests of sprayed tomato fruits using a Joly balance with a flat-tipped needle 50 microns in diameter. The needle was 100 microns in diameter 100 microns from the tip. He made four punctures in each of 20 fruits for each treatment at 8 A. M. The average pressure to puncture was 11.65 grams for the non-sprayed fruits, 11.71 for red copper oxide-sprayed fruits, and 13.93 for bordeaux-sprayed fruits. The difference between the bordeaux and the other two was statistically significant by analysis of variance.

It is suggested that the hardening of tissue occurs because calcium hardens the pectin of the middle lamella as suggested by Kertesz *et al.* (23) in researches on calcium in canned tomatoes.

The fact that the depressing action of bordeaux occurs chiefly on young plants ahead of and during blooming suggests two factors, dwarfing and defloration. Both of these have been shown to be important factors in the field (20). The dwarfing appears to result from the hardening of the cells so that the expansion phases of growth are interfered with. The explanation for defloration has not yet been derived.

In any case both dwarfing and defloration reduce fruit set and this reduces the load of pickable fruits with its interesting results on the slope of the picking curves.

The results on the nature of bordeaux dwarfing suggested immediately the use of lime-free copper compounds. Red copper oxide was first used experimentally as a dust for tomatoes in the summer of 1932. Later work with the material and with other so-called fixed copper compounds has shown that the materials are all some-

TABLE 3. LABORATORY DATA ON SOME COPPER FUNGICIDES

Trade name	Descriptive name of active agent	Probable nature of inert	Copper content percent	Bordeaux coefficient	Tenacity coefficient
Bordeaux	Hydrated basic copper sulfate	Calcium sulfate	....	1.00	0.924
Basicop	Basic copper sulfate	None	51.4	0.047	0.625
Compound A	Basic copper chloride	Calcium salts	46.2	0.443	0.506
Coposil	Copper aluminum silicate	Calcium salts	20.3	0.174	0.206
Coposil CDV	Copper aluminum silicate	Calcium and zinc salts	21.4	0.319	0.333
Cuprocide (red)	Electrolytic red cuprous oxide	None	87.2	0.045	0.855
Cuprocide (yellow)	Electrolytic yellow cuprous oxide	None	....	0.118	0.834
Cuprocide 54	Electrolytic red cuprous oxide	Protective colloid, calcium salts	49.6	0.036	0.480
Cuprocide 54Y	Electrolytic yellow cuprous oxide	Protective colloid, calcium salts	47.4	0.118	0.760
Cupro K	Basic copper chloride	Protective colloid, calcium salts	24.6	0.032	0.500
Hydro 40	Hydrolyzed basic copper sulfate	Calcium sulfate	24.2	0.110	0.340
Oxobordo	Hydrolyzed copper sulfate, basic	Casein, calicum	12.11	0.870	0.080
Tennessee 34	Hydrolyzed basic copper sulfate	Calcium sulfate	35.3	0.068	.660
ZO	Hydrated copper aluminum silicate	Silica, aluminum silicate	25.8	0.191	0.316

what injurious to tomatoes, but that they are much less injurious than bordeaux mixture. It seems probable that the copper acts in somewhat the same fashion as calcium in producing injury, but that it is much less active.

Performance of Fungicides

If the protective action of bordeaux on foliage diseases is to be duplicated or improved without injury, it becomes imperative to investigate how and why fungicides act as they do and how new materials can be fitted into the knowledge thus learned.

Many lime-free copper compounds (Table 3) have been put forward as bordeaux substitutes. Since these perform differently in the field, as might be expected their properties had to be determined and studied piecemeal.

The ability of a fungicide to protect plant parts in the field has been defined as protective value (21). The two prime factors that govern protective value are fungicidal value (i. e. spore-inhibiting power) and tenacity (i. e. resistance to weathering). These two factors can be investigated easily in the laboratory where many of the extraneous factors encountered in the field can be controlled.

A considerable number of researchers have measured fungicidal (fungus killing) value in the laboratory for various materials and have attempted to correlate it with the protective value in the field. The partial lack of correlation has lead some pathologists to feel that laboratory testing is worthless.

The problem has been studied extensively for several plant diseases. The underlying technical considerations are being published by Dimond *et al.* (4) as an accompanying bulletin. The usefulness of these considerations in the control of the defoliation diseases of tomatoes with copper materials will be discussed here. Some of the sources of error in studying fungicides on tomatoes will be discussed.

Fungicidal Value. The first prerequisite to a study of the spore inhibiting properties of insoluble fungicides was to develop a precision laboratory sprayer and the correlative precision techniques (19). Briefly, the materials are suspended in water and sprayed under standard conditions of humidity, time and distance to a standard surface of cellulose-nitrate on glass. Spores of the test fungus, *Macrosporium sarcinaeforme*, are applied in standard concentrations, in standard amounts with a standard pipette in a standard fashion. This assures known and reproducible numbers of spores in relation to known and reproducible amounts of toxicant.

After incubation under standard conditions the spore inhibition is determined microscopically and expressed as percent. Using the Wilcoxon and McCallan (45) simplification of the Bliss statistics, the percentage inhibition is readily plotted against dosage on logarithmic probability paper and the amount of material to inhibit 50 or 95 percent of the spores is read off directly.

Because of biologic variation and experimental error these values vary from test to test. Spore concentration is such a variable, as it

cannot be regulated very easily. Variability can be reduced but not eliminated by using a ratio of performance between the test material and a standard such as bordeaux mixture to give a bordeaux coefficient (19) as follows:

$$\text{Bordeaux coefficient} = \frac{\text{Dosage of standard bordeaux for 95\% inhibition}}{\text{Dosage of test material for 95\% inhibition}}$$

A bordeaux coefficient of 1.00 means that the test material is just as active as bordeaux. If below 1.00 the activity is less and, if above 1.00, the activity is greater.

The fungicidal value so determined for a series of copper fungicides is given in Table 3. The wide differences are interesting and significant. Detailed studies have shown that some of these differences can be explained by differences in particle size. Yellow cuprous oxide contains much smaller particles than red cuprous oxide (10) and of course is more potent. The study of this relation showed that the wave-length of reflected light was related to potency. Particle size decreased and potency improved as the wave length shortened and the color shifted from red to yellow.

It was then found that the basic copper compounds reacted similarly. As the wave length shortened (green through blue to violet), potency increased (17). It is not known whether this phenomenon is associated with particle size or not. It is true, however, that when green Basicop was ballmilled wet for two weeks it became more blue and the potency improved. Since this information was published the manufacturers have taken the green grade off the market and have substituted a blue grade.

It is noteworthy that the curves for cuprous oxides and cupric salts cannot be superimposed. For equal potency the copper as cuprous oxide reflects a longer wave than the copper as a cupric salt. This is evidence on the hypothesis that cuprous copper is more potent as a fungicide than cupric copper (21).

It must not be concluded that protective value is a function of color of the copper material, because tenacity must be considered in field performance.

Tenacity. Fungicidal deposits must not only have spore killing properties; they must maintain these properties in the face of drastic washing. They must cling to plant surfaces while being buffeted by wind and rain. Heuberger (5) has devised a laboratory test for tenacity and a tenacity coefficient comparable with bordeaux coefficient for converting the raw data to usable form. In order to speed the work and to simulate the swaying action of rain-lashed leaves, deposit-bearing slides are placed back to back and passed rapidly through water for a standard 20 strokes, 10 forward and 10 backward, the slides being raised from the water and shaken after each stroke.

The tenacity coefficient is the percentage of initial toxic load that is not washed off by the standard test. The fungus indicator

measures not only the quantity removed, but also the spore inhibiting properties of the deposit that is left.

The tenacity coefficients for the series of copper materials used on tomatoes are given in Table 3, correct up to 1940.

It has been shown (7) that the tenacity test in the laboratory gives results that are in essential agreement with field results with several of the copper materials.

Protective Value. The enormous variability of field results is impressive when comparing the protective values of fungicides whether on tomato, apple or other foliage. The field results are often so variable that a set of materials seldom arranges itself in the same order from test to test. This source of error accounts for some of the discrepancy between laboratory and field results. Methods were needed for reducing this variability, or of understanding it. Considerable progress had been made in designing methods for reducing just such variations in fungicidal value as determined in the laboratory (19). These findings have been applied to problems of measuring protective value in the field and they appear to be exactly homologous as recently discussed (4).

It is apparent immediately that field comparisons have been based on the control for equal dosages of materials, whereas laboratory comparisons have been based on dosage for equal response. It is also apparent that no use has been made of the performance of a standard fungicide in the field to give a figure comparable to bordeaux coefficient for fungicidal value data.

In 1940 (4) it was learned that dosage-response data for field tests give straight lines when plotted on logarithmic-probability paper. Trials were made of the effects of using dosage for equal control as it is used in the laboratory. It soon developed that dosage for equal control is more sensitive and more informative than control for equal dosage (13). Control for equal dosage has a low order of sensitivity because the control scale is limited by a practical ceiling of 100 percent, whereas, the dosage scale is unlimited.

The control scale is less informative than the dosage scale. Moreover the use of the control scale is based on an assumption that response in percent is linearly related to dosage—that unit change in dosage produces unit change in response. The fact, however, is that the relation is sigmoid. In everyday language this means that change in dosage produces at first a small change in response, then a large change, and finally a small change in response.

The fallacy in the use of the control scale appeared in a practical way in the development of yellow cuprous oxide as a fungicide. The data on fungicidal value obtained in 1938 (10) indicated that approximately twice as much copper as red oxide was required to inhibit the same number of spores as yellow oxide. That is to say the copper in yellow oxide was twice as potent as that in red oxide.

Since the tenacity of the two forms is approximately equal (see Table 3) the protective value should follow in the same order. This was found to be true when the two materials were compared as protec-

tants for pea seed. Twice as much copper as red oxide as yellow oxide, was required to give equal protection of pea seeds against damping-off.

The two materials were then compared as sprays on tomato foliage to protect it from *Alternaria solani*. Following general practice for field work the materials were compared at equal doses, not at equal control as in the earlier tests. The control obtained was 71 and 53 percent, respectively. This ratio is 1.34 to 1, not 2 to 1 as would have been expected. Was the discrepancy due to difference in relative performance of the two materials or to difference in technique of measurement?

This question was approached in 1941 when the two materials were compared in a dosage series on the protection of muskmelon foliage against bird's eye leaf spot caused by *Macrosporium cucumerinum*. The first comparison is dosage for equal control. If the 80 percent control level is chosen, it appears that 15.5 pounds of copper as red oxide is required, but only 7.5 pounds as yellow oxide. This is a ratio of 2.06 to 1, as would have been expected from the data on fungicidal value and data on pea seed protective value. It should be stated that the ratio between the two remains 2 to 1 irrespective of what level of control is chosen. This shows that the dosage scale provides an invariable measure of performance.

The other comparison is control by the same dosage. The control is 83 and 90, respectively, for red and yellow oxide for 20 pounds of copper per acre for the season. This is a ratio of 1.09 to 1, not 2.06 to 1. Furthermore this ratio changes with the dosage level chosen. At ten pounds per acre the ratio is 1.11 to 1, and at five pounds per acre it is 1.19 to 1.

From this experiment it is clear that the dosage scale is more sensitive because it spreads the materials farther apart than the control scale, and it is more informative and accurate because it gives reproducible results. It is also more useful practically because it reduces the error of field experimentation.

Derivation of Protective Coefficient. The fact remains, however, that copper materials used as tomato sprays have been compared up until quite recently through the control by equal dosages. Since these data are all that are available they must be used for the present in measuring the protective value of the materials in the field despite the sources of errors and the mathematical inconsistencies in the design of the experiments.

The measurement of protective value in the field is beset with all the difficulties that occur in the laboratory, and more besides. In addition to errors introduced by the fungus, the errors that come from inadequate sprayers, soil heterogeneity and method of taking data are important. Finally, there are variations introduced by the weather.

Of these variables only the weather affects the action of the deposit after it is on the leaf. The other variables simply complicate the measurements of the protective value of the deposit in the same

way as they complicate the measurement of spore inhibiting power of fungicidal deposits in the laboratory. It therefore seems probable that the effects of these other variables can be reduced by calculating a protective coefficient in terms of a standard fungicide, as in the case of bordeaux coefficient for the laboratory (19). This calculation is based here also on the assumption that all sources of error except weather tend to operate on the test material and standard alike.

The only difference in procedure is that the calculations of field data for the present must be based on the response scale rather than on the dosage scale. The amount of disease control on plants sprayed with the test material is divided by the amount of disease control on plants sprayed with the standard material (4-4-50 bordeaux). The quotient must serve for the present as the "protective coefficient," pending the accumulation of data on dosage for equal control. If the quotient is greater than unity, the material has a better protective value than bordeaux mixture; if it is less than unity, the test material is inferior to bordeaux.

There is experimental evidence to indicate that protective coefficient appears to cancel out variations in the methods of recording the amount of disease (18). In 1938 four methods were used for measuring disease on the same power-sprayed plots of tomatoes: percentage defoliation as counted, percentage of diseased fruits, index of disease and the reciprocal of green weight per plant. The protective coefficients for red copper oxide obtained from these four kinds of data were 0.77, 0.74, 0.81 and 0.81. For copper oxychloride the coefficients were 0.51, 0.52, 0.58 and 0.41, respectively.

In the laboratory bordeaux coefficient reduces the effect of spore load. Experimental evidence is available for field data likewise show that protective coefficient reduces the variation due to inoculum potential (i. e. disease producing power of the environment). It so happens that red cuprous oxide has been compared for nine seasons with bordeaux, but during the nine seasons the inoculum potential has varied widely. When protective coefficient was plotted against inoculum potential (expressed as percentage defoliation in the checks), a scatter diagram was obtained showing that inoculum potential bears no relation to protective coefficient, and that results in different plots or in different years will not be influenced by variations in the incidence of disease.

Another bit of data (Table 5) confirms this conclusion. Stem-end rot counts were made on five picking dates in 1938. The percentage infection increased on the checks from 6.8 percent to 60.1 percent between August 18 and September 15 as the inoculum potential increased. Likewise the percentage of stem-end rot increased on the plots sprayed with red copper oxide and bordeaux, but the protective coefficient remained approximately constant. At least the variation in the protective coefficient bore no relation to the variation in inoculum potential.

From these various studies it follows that test to test variation

TABLE 4. PROTECTIVE COEFFICIENTS FOR VARIOUS COPPER FUNGICIDES TESTED AS PROTECTANTS AGAINST DEFOLIATION OF TOMATOES

Fungicides	Date of test															
	1932		1934		1935		1936		1937		1938		1939		1940 [1]	
	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.	Percent Control	Protect. Coeff.
Basicop															19.5	.52
Bordeaux	85.0	1.00	83.2	1.00	82.1	1.00	93.8	1.00	60.4	1.00	49.8	1.00	50.4	1.00	37.5	1.00
Compound A											35.0	.77	48.6	.96	21.0	.56
Coposil															12.5	.33
Coposil CDV																
Copper hydro 40																
Cuprocide (Red)	74.8	0.88	87.2	1.05	77.7	0.94	78.7	.83								
Cuprocide (Yellow)									61.8	1.02	40.5	.81	49.6	.98		
Cuprocide 54															27.0	.72
Cuprocide 54Y									67.0	1.11	28.4	.57	42.8	.84		
Cupro K											47.0	.95	52.8	1.05		
Tribasic sulfate (Tenn) ZO									49.4	.78	13.4	.27	41.8	.82	9.5	.25
											32.8	.66				
Check	52.5	....	74.0	....	66.2	....	42.6	....	43.2	....	.4	....	30.6	....	.5	....

[1] This test at New Haven, Conn. The others at Geneva, N. Y.

TABLE 5. RELATION OF INOCULUM POTENTIAL OF *Alternaria solani* AS MEASURED BY STEM-END ROT ON THE CHECK TO PROTECTIVE COEFFICENT (P. C.) OF RED COPPER OXIDE.

Treatment	Stem-end rot, percent, and protective coefficient for different pickings									
	August 18		August 24		August 31		Sept. 8		Sept. 15	
	Percent	Protect. Coeff.	Percent	Protect. Coeff.	Percent	Protect. Coeff.	Percent	Protect. Coeff.	Percent	Protect. Coeff.
No treatment	6.8	....	19.3	....	30.9	....	53.4	....	60.1	....
Bordeaux	7.1	....	18.8	....	17.9	....	15.9	....	38.5	....
Red copper oxide	7.9	0.90	13.8	1.35	20.9	0.85	21.2	0.75	42.9	0.90

in protective value of fungicides in the field can be reduced by using (a) dosage for equal control, (b) protective coefficient.

The protective coefficients as obtained for a series of copper materials during the past several years are given in Table 4. The protective coefficients for the copper fungicides show a wide range among the materials, but it is difficult to see at first that any relation exists between the performance as measured in the field as protective value and the performance as measured in the laboratory as bordeaux coefficient.

Perhaps the most striking hiatus is that for red copper oxide. This material stands low in the list of bordeaux coefficients, but it stands high in the list of protective coefficients. Conversely, Compound A stands high in the list of bordeaux coefficients and only medium in the list of protective coefficients.

Although a complete explanation for these changes in rating is not yet available, inspection of the tenacity coefficients offers considerable help in explaining them. Red copper oxide stands high in tenacity and it stands high in protective value. Compound A stands medium in tenacity and medium in protective value.

These interrelations of tenacity and fungicidal value show how the trend of research on copper materials has been determined. The fungicidal value of red cuprous oxide was raised by reducing the particle size. Yellow cuprous oxide was the result, and it is now much more widely used than red cuprous oxide.

Most of the so-called fixed copper materials are low in tenacity. Research on them is directed toward artificial stickers, and soybean flour, oils and resins are being investigated for these.

Timing. Apple scab control is the classical example of the necessity for precision in timing applications of fungicides. The necessity for early spring applications of fungicides for this disease has been reflected in the thinking on other diseases. As a result the chief emphasis on control of tomato defoliation has been early and mid-season applications despite three important considerations: (a) spray damage is more severe on young than on mature plants (20); (b) the disease is a mid and late season disease and (c) as early as 1920 Martin (25) reported experiments indicating that delayed sprays were essentially as effective as early sprays.

Timing experiments were made in five years when, fortunately, there was enough disease to separate the effect of the various applications. The early tests in 1929 and 1932, made by omitting progressively the late applications, gave preliminary indications (Figure 6 that sprays applied ahead of July 10 in western New York were essentially valueless in disease control. The 1938 and 1939 tests, comparing all-season with late sprays, indicated that early August was somewhat too late to make the first application.

On the basis of these four years' trials, it was obvious that the critical period lay between July 10 and August 1.

A more elaborate timing test was designed in 1940 to test in Connecticut the schedules of various lengths; early, mid-season and late

TABLE 6. EFFECT OF TIMING APPLICATIONS OF YELLOW COPPER OXIDE ON CONTROL OF DEFOLIATION OF TOMATOES CAUSED BY *Alternaria solani*.

Treatment No.	Dates of Application										Disease	Control Percent
	June 21	June 28	July 5	July 12	July 19	July 26	Aug. 2	Aug. 9	Aug. 16	Aug. 23	Aug. 22	Sept. 2
1									X	X	44.4	36.2
2							X	X	X	X	51.7	56.9
3					X	X	X	X	X	X	63.4	56.0
4			X	X	X	X	X	X	X	X	69.4	69.0
5	X	X	X	X	X	X	X	X	X	X	67.8	67.5
6	X	X	X	X	X	X	X	X			64.0	50.0
7	X	X	X	X	X	X					60.0	11.0
8	X	X	X	X							47.4	4.0
9	X	X									42.7	2.5
10					X	X					60.5	15.0
11							X	X			57.4	40.0
12									X	X	40.0	32.0
Non-sprayed											38.0	0.0

(8). Each treatment consisted of four replicate plots of ten plants each of Scarlet Dawn tomatoes, sprayed at 250 pounds pressure with a single nozzle, applying 4.8 pounds of yellow copper oxide in 200 gallons of water per acre.

Spraying began June 21 and continued weekly until August 23. In one series of plots sprays in pairs were dropped from the end of the season to study the effect of early sprays only. In a second series, sprays in pairs were dropped from the beginning of the season to study the effect of late sprays only. In a third series various plots were given two applications one week apart in the middle of the season.

Disease control data (Table 6 and Figure 7) clearly confirm previous conclusions that the critical first application should be applied in mid-July. On the basis of the 1940 data at least, it seems that applications should begin perhaps a week earlier in Connecticut than in western New York.

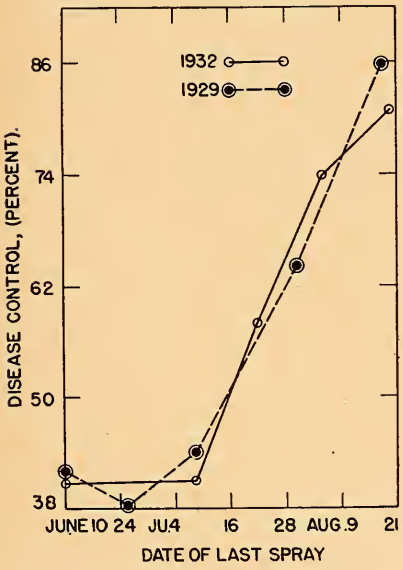

FIGURE 6. Relation between date of last spray and control of defoliation of tomatoes in 1929 and 1932.

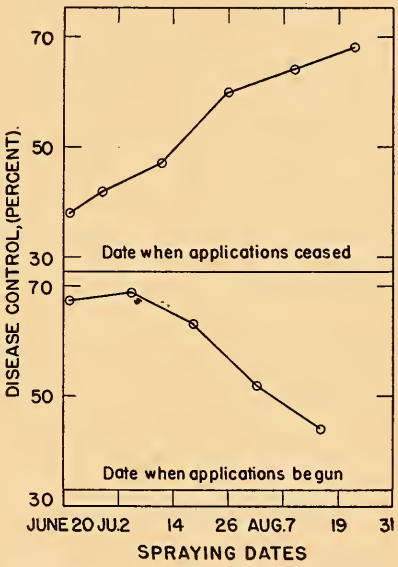

FIGURE 7. Effect of timing sprays of yellow copper oxide on control of defoliation caused by *Alternaria* in 1940.

Practical adoption of the theory of delayed spraying admits the possibility that disease may obtain a start before work begins. It is of interest, therefore, to investigate the effect that such a start has on final disease control. This point was investigated in 1938. Two fields infected with *A. solani* were chosen for spraying on August 3. One showed approximately 5 percent, and the other 20 percent, defoliation (by number of leaves).

At the end of the season the unsprayed portion of the fields

showed 66.4 and 89.4 percent defoliation (by number), respectively. When sprayed with bordeaux, they showed 30.1 and 55.0 percent defoliation, respectively. Plainly, the field that was severely diseased to begin with lost more leaves than the slightly diseased field whether sprayed or not. Evidently bordeaux did not freeze the defoliation at its initial level.

Coverage. If spraying is to be delayed until the last possible moment when the fungus may be already established, it is plain that the protective load of fungicide must be so applied as to cover adequately all susceptible tissue, especially the old somewhat senescent tissue at the base of the plant and inside the foliage crown. Coverage of ground plants would seem to be more difficult than coverage of staked plants.

There appear to be three variables in the application of fungicides by spraying: (1) pressure, (2) nozzle aperture and (3) spraying time. A study, incomplete as yet, is being made of the effect of these variables on unstaked tomatoes (Scarlet Dawn).

In 1940 an initial attempt was made to improve coverage by holding pressure constant and by varying the gallonage per acre of spray fluid. The gallonage was increased by increasing the nozzle aperture and the spray time. It was expected that increasing the nozzle aperture would increase the velocity of the spray stream at the nozzle and that this would force the stream farther through the crown of leaves toward the important inner and basal ones. The plants were sprayed by directing a single nozzle to all parts of the outer crown of leaves, occasionally pushing the nozzle inside. A Myers wheelbarrow power sprayer provided the yellow copper oxide at 250 pounds pressure. Four applications were made between July 24 and August 23. Disease readings were made on September 7 (Table 7).

Table 7. Effect of Coverage by Yellow Cuprous Oxide Spray on Control of Defoliation of Tomatoes Caused by *Alternaria solani.*

Nozzle		Spray time	Spray applied	Copper applied as metallic		Disease control
Aperture in.	output gal./min.	secs./plant	gals./acre	lbs./100 gal.	lbs./acre	percent
5/64	0.73	13	375	4.0	15.00	54.8
5/64	0.73	13	375	2.0	7.50	48.2
5/64	0.73	13	375	1.0	3.75	44.4
5/64	0.73	13	375	0.5	1.88	34.6
4/64	0.58	6	150	4.0	6.00	28.7
4/64	0.58	6	150	2.0	3.00	22.0
4/64	0.58	6	150	1.0	1.50	11.8
4/64	0.58	6	150	0.5	.75	11.8
3/64	0.43	3	60	4.0	2.40	12.4
3/64	0.43	3	60	2.0	1.20	13.4
3/64	0.43	3	60	1.0	0.60	2.5
3/64	0.43	3	60	0.5	0.30	3.4
....	....	....	none	0.0	0.0	1.2

Data were plotted (Figure 8) on log-probability paper using dosage as pounds of copper per acre. Alternaria attacked early and heavily and spraying began somewhat late. On this account no treatment gave very good control. In the first analysis of the data the effect of the three gallonages was determined on the basis of dosage for equal control (13). The level of control that fits all three the best is 25 percent. This level of control was provided by

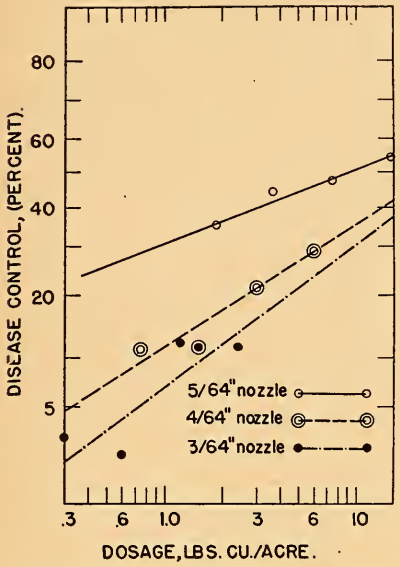

FIGURE 8. Effect of coverage with yellow copper oxide spray by using various sizes of nozzles on control of defoliation of tomatoes by *Alternaria solani.*

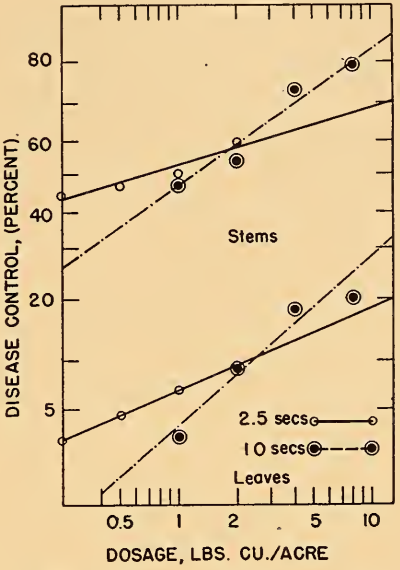

FIGURE 9. Relation of spraying time (seconds per plant) to coverage by yellow copper oxide spray on the control of defoliation of tomatoes caused by *Alternaria solani.*

0.48 pounds of copper per acre per application when applied in 375 gallons of water through the large aperture. The requisite dosage increased by ten fold to 4.5 pounds when it was applied in 150 gallons of water with the medium disc. The requisite dosage increased further to 6.4 pounds when it was applied in only 60 gallons of water with the smallest disc.

An unexpected result appeared in the data. The slope of the dosage response curve became flatter as the coverage improved (Figures 8 and 9). Dimond (3) has shown that this slope is a linear function of coverage and he suggested that the slope of the curve offers a convenient measure of coverage.

This experiment in 1940 was interesting and probably significant, but it involved a confusion of the effects of nozzle aperture and spray time. In 1941 a similar experiment was conducted except that the

nozzle aperture (3/64 inch) and pressure (250 pounds) were both held constant. Spraying time was varied.

Alternaria attacked very heavily. Leaf disease readings were made on September 2 as usual (Table 8), but readings were made on stems as well, since these were heavily attacked also. In the case of stems, the groupings were made on the proportion of area covered by spots on the lower foot of stems.

TABLE 8. RELATION OF SPRAYING TIME TO COVERAGE BY YELLOW CUPROUS OXIDE SPRAY ON THE CONTROL OF DEFOLIATION OF TOMATOES CAUSED BY *Alternaria solani.*

Spraying time secs./plant	Amount of spray applied gals./acre	Amount copper expressed as metallic		Disease control percent	
		lbs./100 gals.	lbs./acre	Leaves	Stems
20	400	4	16	16.7	85.2
20	400	2	8	22.0	77.0
20	400	1	4	6.7	65.5
20	400	0.5	2	4.2	55.7
10	200	4	8	19.7	79.0
10	200	2	4	19.2	73.0
10	200	1	2	9.5	52.7
10	200	0.5	1	4.5	45.5
5	100	4	4	14.2	67.7
5	100	2	2	9.7	60.5
5	100	1	1	6.7	60.0
5	100	0.5	0.5	3.0	45.7
2.5	50	4	2	9.2	60.5
2.5	50	2	1	6.5	49.8
2.5	50	1	0.5	4.5	46.5
2.5	50	0.5	0.25	3.0	44.0

Data (Figure 9) were plotted as usual on the basis of pounds of copper per acre per application. To save cluttering the graph only the first and third spray times are plotted (2.5 and 10 seconds per plant). Data for the foliage and the stems are in excellent agreement. As the spraying time per plant increases, the slope of the dosage-response curve increases. If slope measures efficiency, as deduced from the 1940 data, it follows here that the long spray times were relatively less efficient than the short spray times per unit of copper per acre.

This seems reasonable. Increasing the spray time increases the run-off, and this means that much of the copper applied with a long spray time runs off onto the ground where it cannot protect foliage.

On the basis of this discussion it follows that the improved efficiency with increasing gallonage noted in 1940 was due rather to the use of larger nozzles than to increased gallonage directly. The larger the nozzle aperture, the greater the nozzle velocity of a spray stream, other things being equal as they were here. The higher the velocity of the spray stream, the more the outer leaves will be pushed aside, so that the inner ones may be covered.

Search of the literature has revealed little that is apropos here. The effects of pressure and nozzle aperture have been studied, but

not in connection with the dosage-response technique. Farmers are certainly trending toward larger nozzles with fewer gallons per acre, and away from small nozzles and much gallonage per acre. Smith and Zimmerley (34) constitute a typical case. They tested the effect of pressure in spraying tomatoes in 1922. Their data are difficult to evaluate in this connection because they report no disease readings and because they have not distinguished dosage of copper per acre from pressure.

Morris, Klotz and Sokoloff (29) published a paper late in 1941 giving results with bordeaux in the control of brown rot on citrus. They applied only two concentrations and two gallonages but, when their data are calculated as amount of copper per tree and plotted on log-probability paper, two curves appear. The higher slope of the curve for the gallonage is the flatter of the two as would be expected if it had given improved coverage. These writers do not state, however, how they obtained the larger gallonage per tree.

PRACTICAL ASPECTS

Since Agricultural Experiment Stations are the research laboratories of farmers, the final objective of its research must be the practical application. The defoliation problem is intensely practical. The question here is whether it can be helped by the present investigation.

To Spray or Not to Spray

The first question is "to spray or not to spray." This question like many others in science cannot be answered categorically. To that end it is well to summarize here the factors that can help an individual farmer to decide that for himself.

The farmer who sells in a quality market and who is troubled with much defoliation will find a marked improvement in quality for spraying. Although spraying will probably not greatly improve the total tonnage, it will improve the tonnage of salable fruit. Spraying will do much to guarantee rich red tomatoes that sell well in a quality market. It will reduce the amount of stem-end rot, anthracnose, cracking, blossom-end rot and flabbiness.

The farmer who sells extra early fruit cannot afford to spray, because most of the fruit that he sells at a fancy price is sold before disease becomes serious. Spraying will tend to reduce yield slightly, and disease is seldom serious enough to offset this in the early crop.

On the contrary, the farmer who sells to the extra late market often finds that defoliation is serious enough to reduce his yield of marketable fruit and often forces him to reduce even his quality standards in order to have any fruit at all available for sale. Judicious spraying in late July and August will maintain sufficient foliage in late September to produce quality fruit that is salable.

Materials to Use. As yet no effective agent other than copper is available for use on tomatoes, although organic compounds were

investigated somewhat in 1940 and 1941. Sulfur seems to dwarf the plants. Accordingly copper fungicides must receive the bid. Since lime is distinctly deleterious to tomatoes, bordeaux mixture can hardly be expected to be chosen, except as noted below.

This narrows the field to the so-called insoluble or "fixed" (41) copper materials. These have been studied in considerable detail. Some of these have shown themselves distinctly inferior to others in disease controlling powers on tomatoes. These are Cupro K, Z-O, Metrox, hydrated cupric oxide and Cuprocide 54.

Others have shown themselves invariably toward the top of the list as follows: Yellow copper oxide (Cuprocide), red copper oxide (Cuprocide) and copper oxychloride (Compound A). In one year when it was tested Tennessee Tribasic copper sulfate stood toward the top of the list.

The other materials have not been tested sufficiently to arrange them with too much certainty, but the only one that looks as if it would find a place high in the list is Coposil, and it, unfortunately, is too injurious to tomatoes.

In Connecticut where flea beetles are a problem, it seems that a rotenone or dry Pyrocide dust would be useful in keeping them down. This would prevent the eating injury where the fungus spores may gain entrance to the leaf.

When to Spray. It seems clear now that attention to timing may save on materials and add to the value of the applications. In the past, applications have gone on the plants early in the season when they were most injurious and least required. It seems better to apply them later in the season when they are least injurious and most required.

The generalization seems sound. Its application to specific cases raises many knotty problems. Timing tests were made in New York in 1929, 1932, 1938 and 1939 in plants set out the third week of May. The tests in 1929 and 1932 showed that sprays ahead of July 10 were worthless. In 1938 and 1939 an arbitrary date of August 1 was set, but in both years it was somewhat too late. It would appear that the critical date was between July 10 and August 1.

A timing test was made at New Haven in 1940 using plants set out about May 23. The results indicated that July 10 was early enough for the first application. If a similar test had been made in 1941 this date would have been close to optimum.

From these various timing tests in two areas with similar growing seasons, it would seem that the first spray should be applied about July 10 for maximum disease control. This date is based on work with crops planted into the field about May 20. In 1941 the crop was set about May 10 and spraying had to begin about July 1.

This suggests that timing should be based on the stage of the plant rather than calendar date as in the case of apple scab. Actually, it seems from experience that the sprays should be applied just ahead of the "break" stage, i. e., the stage when the weight of the plants begins to break them over, so that the inner leaves begin to be shaded

and protected from drying out. An application at this stage is easy to apply because the lower leaves are still exposed, and the plants are not spread out over the ground between the rows.

The number of delayed applications is also important. Here again the final answer is not in, but it seems probable that three at ten-day intervals is enough. In some years one good application would be enough, because growth slows down after August. If the spray has good tenacity, the susceptible foliage would remain covered long enough.

How to Apply Materials. The methods of applying fungicides raise many unsolved problems. Vegetable growers prefer dusting, although spraying has given the best disease control so far in this research. Since the program calls for delay until the last moment, the fungus may get such a start as to make it imperative to use the best possible procedures. Spraying is, therefore, preferred. Additional research is now under way to improve dust mixtures and methods of application.

Whatever the machine used, the problem remains of getting through the fields after the plants have filled the rows. Farmers in cannery areas report some success with airplane applications. Fields are too small for this in Connecticut.

Other growers lay out the roads for picking earlier than usual, throwing the vines together. Sprayers with long booms are driven through these roads. Other growers make the roadways farther apart and carry a very long boom by hand. If the number of applications can be trimmed to one or two this might be a feasible procedure.

From two years' results it seems that the problem of covering the inner lower foliage of ground plants is critical, and it now seems clear that large holes in the nozzles giving a strong drive to the spray stream should give better success than small holes giving a misty spray. On the basis of present information it is suggested to at least three pounds of copper (as metallic) should be applied per acre per application in a minimum of 200 gallons of water with 5/64 inch discs.

Varieties

As far as can be determined, no tomato variety shows any marked resistance to the Alternaria defoliation. In a variety trial, the entries show large differences in defoliation, but careful study shows that these differences are associated with fruit load. Early varieties set fruit early and become defoliated early. Late varieties set fruit late and become defoliated late.

Fertilizers

Information on the relation of fertilizers to Alternaria defoliation is yet insufficient to make definite statements, but evidence now available points to an influence of nitrogen. Low levels of nitrogen nutrition encourage disease. Increasing the nitrogen nutrition is liable

to reduce fruit set and, of course, to reduce total yield. If disease attacks, however, a high level of nitrogen nutrition might permit the field to pull through a marketable crop that might otherwise show such poor quality from disease as to be almost unpickable.

Air Drainage

Other things being equal, tomato fields on slopes, especially southern and western slopes, probably have less disease than those without as good air drainage. Staking, of course, improves air drainage and reduces severity of the defoliation disease.

Miscellaneous Suggestions

Since the disease is seed-borne, the seed should be from certified sources and it should be soaked in New Improved Ceresan 1-1000, dried and dusted with red copper oxide. To prevent development of disease in the seed bed, the seedlings should be sprayed at weekly or ten-day intervals with the material to be used in the field.

The fungus also lives over winter in field refuse. Accordingly, a rotation of at least two years will keep down this source of inoculum. Finally, it may be spread from plant to plant if plants are picked or cultivated when they are wet.

SUMMARY

1. A study has been made during 12 seasons of the foliage and fruit diseases of tomatoes with the objective of exploring the whole field of defoliation diseases of tomatoes. Particular emphasis has been devoted to solving the paradox of reduced yields from sprays despite disease control. This paper reports data on the effects of disease on the plant and the interacting effects of sprays and disease on yields.
2. The problem has been attacked by studying plants in various stages of disease and by studying the varying control obtained by different sprays.
3. The primary cause of defoliation in the Northeast is *Alternaria solani*, but since this fungus is not what may be called a vigorous parasite, optimum conditions must prevail before attack sets in.
4. Optimum conditions for the disease include: (a) crowded plants, (b) maturity of leaves, (c) heavy fruit load, (d) above normal rainfall and dew and (e) shading. Disease, of course, may appear when one or more of these conditions are not fulfilled, but they all seem to play a part.
5. A special study was made of the relation of fruit load and age of tissues to susceptibility and it appears that any factor such as pruning, low nitrogen nutrition or heavy reproduction tends to increase susceptibility. This is especially striking in the case of fruit load. The longer the plant remains free of fruit, the longer it remains free of Alternaria; and the more fruit it sets, the more susceptible it becomes.
6. An extensive study of the effects of disease and spraying on

ripening has been made. No evidence can be found that indicates any effect on the maturity of fruits, i. e. ripening. Many factors such as disease, dwarfing and defloration from sprays reduce fruit load. These factors affect, of course, the number of fruits picked and thus they affect the shape of the picking curve.

7. In studying yields the problem arises of what constitutes ripening. Ripening is defined as reddening. Accordingly, many fruits that have been picked as ripe on defoliated plants were not ripe because they were orange in color and never would have become red.
8. Since this point was not clarified until after the completion of the current research, many fruits have been picked on defoliated plants as ripe when they were not ripe in the same sense as those on plants not defoliated. As a result picking data have tended to favor defoliated plants unduly.
9. In studying the disease-controlling properties of fungicides, a protective coefficient has been devised for reducing the variance between tests that is due to inoculum potential, spraying technique, method of recording disease and kind of disease. Although this statistic has some weaknesses, it serves the useful purpose of eliminating the effect of many confusing variables. It is the quotient obtained by dividing the amount of disease on plants sprayed with a standard by that on the test material. It is based on the assumption that as extraneous factors affect the unknown they also affect the standard.
10. One or more tests have been made of copper-containing bordeaux substitutes. Insufficient data are available to rate them all with precision, but three groups seem possible: good, intermediate and poor. Those in the "good" group appear to be yellow copper oxide (Cuprocide Y), bordeaux, red copper oxide (Cuprocide G), Compound A, Coposil and Tenn. 34. Those in the "intermediate" group are Basicop, Hydro 40 and Cuprocide 54. Those in the "poor" group are Metrox, ZO, Cupro K and hydrated cupric oxide.
11. Timing of tomato sprays is of critical importance in economical control of defoliation. Since no spray is completely non-injurious, and since injury is most pronounced on small plants, the applications should be delayed as long as possible. On the other hand, the longer the sprays are delayed, the less effective they can be in stopping an outbreak. Consideration of all the data suggests that the first application in Connecticut should be applied just as the plants break over.
12. Coverage becomes an important factor in spraying ground tomatoes because the lower and inner leaves are the most susceptible of any to defoliating fungi. Although evidence is somewhat limited, it appears now that insufficient attention has been paid to size of nozzle orifice. This should be as large as possible so that the spray stream will be hard enough to push aside the outer crown of leaves.

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